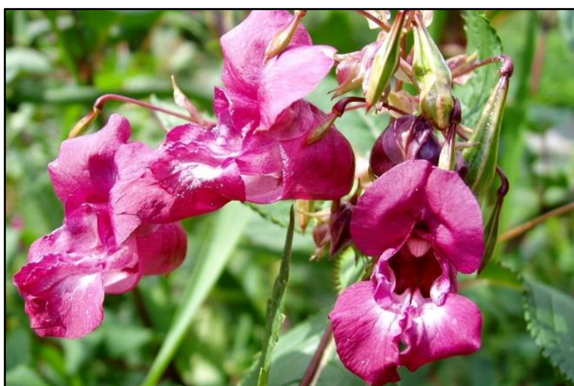
INVASIVE PLANT SPECIES MANAGEMENT

FOR THE CITY OF THUNDER BAY

by

Matthew Jordan



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Faculty of Natural Resources Management

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ABSTRACT

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Non-native plant species are being introduced into new environments at an increasing rate due to globalization and increased levels of trade. As such, the field of invasive plant management must constantly evolve in order to adequately manage the rising number of threats. The impacts caused by introduced species and how introduced species become “invasive” is examined to better understand the threat they pose. Discussions pertaining to the multiple control methods and their various advantages and disadvantages are done to identify solutions applicable at a local scale. Management strategies and control methods for various invasive species found within the city of Thunder Bay are examined to provide recommendations for the city.

CONTENTS

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INTRODUCTION

The rise of globalization and an increase in global trade has paved the way for an increase in non-native species being introduced (Holmes *et al.* 2009; Hulme 2009). However, as discussed by Tobin (2018) and Valéry *et al.* (2008), not all introduced species are invasive, and the term "introduced species" generally has a negative connotation attached to it. What makes a species "invasive" is often the source of debate, and many papers have attempted to classify them. Valéry *et al.* (2008) describes an invasive species as any species that "becomes dominant, in density and/or biomass, in its novel environment." These species are detrimental to the environment, economic interests, and public health (Sagoff 2018; NOAA 2019). Russell and Blackburn (2017) summarized an invasive species as being "defined by their negative impact". Yet, there is still debate between researchers on standardized terminology for invasive species and that it is difficult to evaluate what makes a species "harmful" (Heger *et al.* 2013; Simberloff *et al.* 2013). The study of invasive species, and the management of them, is called "invasion biology" which looks at the impact and effects of invasive species (Heger *et al.* 2013; Simberloff *et al.* 2013; Sagoff 2018). Simberloff (2013) describes the process in which a species, introduced with human assistance (deliberate or not), spreads from the place of origin to a new environment as a "biological invasion". Valéry *et al.* (2008) differentiates a "biological invasion" from a regular "invasion" of a species - which is classified as the extension of a species over time (*i.e.* the colonization of a species after glaciation) - by characterizing a biological invasion based on the swift distribution and establishment due to competitive advantages over native species.

SPECIES INTRODUCTIONS

Understanding the avenues in which invasive species enter a new region is fundamental in preparing a management plan. Paini *et al.* (2016) examined the overall global threat to agriculture from invasive species and determined that the United States and China represented the largest importers for the rest of the globe; the study hypothesized that these two countries represent the central nodes for the invasive species spread. These species are introduced with the assistance of humans, either inadvertently via trade or travel, or purposely for ornamental reasons (Winberry and Jones 1973; Pascal *et al.* 2010). With an increase in globalization, the rate of spread for these species has increased due to access to technology and new ways to conduct trade (Gaston *et al.* 2003; Hulme 2009; Paini 2016). The advances in technology have opened new routes for invasive species to be introduced and in a study done by Humair *et al.* (2015), the emergence of internet trade has played a roll in the number of introductions. The study found that that the international horticultural community was highly responsible for the trade of invasive plants (Humair *et al.* 2015). Around 40% of invasive plants used in this study were being sold online; the study admits that, although the trade of invasive plants through e-commerce represents a small fraction of total plant trades, it represents a significant problem in the implementation of management plan because of the dynamic structure of online marketplaces which makes it hard to track and monitor all trades (Humair *et al.* 2015).

The size and speed of cargo ships has increased to the point where global imports have increased by fou times since 1970 (Hulme 2009). When countries rely heavily on imports – such as island nations – they face a higher risk of biological invasion (Hulme 2009). The increasing globalization and rise of international commerce – and e-commerce - have made the management of invasive species hard, but, as discussed by Paini *et al.* (2016) and Humair *et al.* (2015), the burden of management needs to be shared by the international community. The assessment of any biological invasion is reliant on the knowledge of the place of origin, and with the increased productivity of global shipping enterprises it is hard to accurately and conveniently monitor this (Hulme 2009).

There are many examples of species being introduced accidently that caused huge irreparable damage to the biodiversity, the economy, and cultures of humans. The emerald ash borer (*Agrilus planipennis* Fairmaire) or the fungal pathogen that causes chestnut blight (*Cryphonectria parasitica* (Murr.) Barr.) represent some of these examples. Emerald ash borer has decimated the population of ash tree species (*Fraxinus* spp.) across eastern North America and is beginning to travel west; the decline of the species is problematic as ash trees represent a large proportion of natural forest stands and are one of the most widely used urban trees in municipalities (Poland and McCullough 2006). Holmes *et al.* (2009) discusses the impact a biological invasion has on the local biodiversity by examining the decline and disappearance of the American chestnut (*Castanea dentata* (Marsh.) Borkh.) following a series of alien species introductions after European settlement.

Some species are introduced purposely and later become invasive. An example of this is kudzu (*Pueraria montana* (Lour.) Merr.), which was intentionally introduced to

North America originally as an ornamental but later as a forage crop and to help establish slopes and prevent erosion (Winberry and Jones 1973; Holmes *et al.* 2009). The plant, sometimes called the “foot-a-night vine”, has inadvertently caused millions of dollars of losses to timber productivity by invading forests and killing saplings and mature trees and by covering the forest floor and preventing regrowth (Winberry and Jones 1973).

IMPACTS OF INVASIVE SPECIES

The impacts of invasive species have many different appearances, and largely depends on the habitat type that the species are associated with. Impacts can include the loss of productive lands (*e.g.* agricultural lands), the devaluation of houses and properties, and the loss of aesthetic values in parks and gardens (OMNR 2012; Onen *et al.* 2017). The lost of biodiversity caused by invasive species such as kudzu replacing native species represents a large problem with invasive species management (Krcmar 2008).

Overall, the driving force of invasive species management is largely economic and is most likely attributed to the impact on the agricultural industry (Howard 1929; Tobin 2018). The lost of economic value for many agricultural industries due to introduced species forced the hand of the government and money was quickly put towards the protection against these species (Howard 1929). The economic impact caused by the destruction of these introduced species for the agricultural sector in the United States is roughly USD $40 billion per year (Paini *et al.* 2016).

Economic impacts were also felt in the forest industry through the elimination of species due to competition or, in the case of the American chestnut, an introduced pathogen. American chestnut was a common tree species of eastern North American forests and at one point represented up to 40% of standing timber in forest stands in eastern North America; chestnut blight was first discovered in 1904 and over the next 40 years wiped out nearly 4 billion trees (Hepting 1974; Myers *et al.* 2004; Holmes 2009; TACF n.d). The economic impact caused by these introduced species played a large role in the public perception of invasive species and demonstrated the need for management.

The impact caused by chestnut blight left ripples on the culture of many people – specifically for those in the Appalachian region – for decades (Myers *et al.* 2004). George Hepting (1974), an American forest scientist, discussed his first-hand experience of the decline of the American chestnut through a series of anecdotes about how the collection of the chestnuts represented a large part of the culture of rural communities and that "the farmers' hogs were fattened on chestnuts, and, to no small degree, his children were also". Hepting (1974) continued to explain one of the key issues with combating invasive species spread which was the importance of fast action.

The disease was first discovered in 1904 but it was not until 1909 that governmental bulletins began to describe it as a new species, likely because of the time it took to conduct the required research (Hepting 1974; Davis 2005). However, during this time the disease had spread rapidly and millions of dollars of chestnut timber was destroyed and/or devalued (Hepting 1974). The impact not only left ripples in the economy but on the local biodiversity and forest structure (Myers *et al.* 2004; Davis 2005; Holmes *et al.* 2009).

Following the decimation of the American chestnut there were significant changes in the forest structure and in the interactions of the ecosystem. Studies done by Stephenson (1986) and Myer *et al.* (2004) examined the change in forest structure following chestnut blight; canopy structure was not the only thing that was impacted.

A study done by Diamond *et al.* (2000) explored the decrease in the production of hard mast (*i.e.* nut production) following the introduction of chestnut blight. The study determined that there was approximately 34% less hard mast production following the outbreak of chestnut blight.

The introduction of the pathogen and subsequent destruction of the American chestnut also had lasting effects on the ecosystem structure. Following the decline and removal of chestnut, forests in eastern North America experienced a decreased quality of litter inputs and production and an increase of woody debris in streams – even decades after (Hedman *et al.* 1996; Wallace *et al.* 2001). Overall, the economic damages caused by invasive species is felt in numerous industries and a study done by Pimentel *et al.* (2005) estimated that the cost from managing these species and the losses incurred from them totalled roughly USD $120 billion per year.

Along with the impact on trade and the economy, invasive species also affects the value of properties. There have been multiple studies done that look at the effect invasive species have on property values, and the results show that invasive species result in a depreciation of the property (Holmes *et al.* 2006; Zhang and Boyle 2010). In the study done by Zhang and Boyle (2010), which examined what level of impact Eurasian Water Milfoil (*Myriophyllum spicatum*) had on property value, they found that depending on the level of invasion, the property value was lowered between 1-16%. Holmes *et al.* (2006) hypothesized that because trees had a positive impact on property value, then things that affected them would lower the value. The study concluded that there was an association between reduced property value and level of damage caused by the invasive species (Holmes *et al.* 2006).

The threat of extinction for threatened species has slowly crept up the list of concern for many people, and as described by Jared Diamond (1989), there exists an "Evil Quartet" of causes for extinction of species. Habitat destruction and fragmentation, over-hunting and overexploitation, secondary extinctions (*e.g.* the change in predator-prey dynamic), and the introduction of non-native species with habitat destruction being the primary driver. But Diamond (1989) hypothesized that with the increase in global trade, then the impact of invasive species would play a large role in the extinction process. In a recent study done by Bellard *et al.* (2016), it was shown that introduced species represented the second most common threat of extinction for species that have gone extinct since 1500 AD. The study concluded that for three of the five taxa examined under the study, introduced species represented the greatest cause for extinction. However, plants represented the taxa with the least amount of associated extinctions – the study stated that 15 of 55 plant species declared extinct by the IUCN Red List listed introduced species as the cause for extinction (Bellard *et al.* 2016). Overall, studies have shown and agree that following habitat loss, introduced and invasive species play the largest role in the extinction of species (Diamond 1989; Walker and Steffen 1997; OMNR 2012; Bellard *et al.* 2016).

ESTABLISHMENT OF INVASIVE SPECIES

Introduced species do not always become invasive, however, there have been many studies conducted to examine the circumstances surrounding the establishment of invasive species. Allendorf and Lundquist (2003) hypothesized that the establishment of invasive species is a two-part process. First, the biological invasion of species occurs and the new species is introduced into a novel environment where it must survive. Second, the species must begin to replace native species; replacing native species requires the introduced species to outcompete the native species for valuable resources. Similar genetic principles that apply to the conservation of threatened species can be used to identify whether an introduced species will become invasive. These principles, as discussed by Allendorf and Lundquist (2003) are: (1) genetic drift and the effects of small populations, (2) gene flow and hybridization, and (3) natural selection and adaptation.

Propagule pressure, which measures the number of individuals from the introduced species that are released into a region, is a way to examine the potential establishment of a species and, by extension, outlines the chances of control versus elimination of the species (Allendorf and Lundquist 2003). If there are a large number of individuals introduced into an area, the pressure is greater which increases the rate of spread while decreasing the lag period of establishment. A larger number of introduced individuals can mitigate the effect caused by a population bottleneck by increasing the overall genetic variation, therefore, increasing the ability for the species to adapt to the environment (Allendorf and Lundquist 2003). Plant species have a particular ability to avoid issues caused by reduced genetic variation due to specialised means of reproduction. Calzada *et al.* (1996) and Baker (1995) recorded that many invasive species are able to reproduce asexually via apomixes or through vegetative reproduction which removes the risk of inbreeding depression (Barrett and Husband 1990).

Many reasons have been proposed for why certain introduced species are able to establish and become invasive. One hypothesized reason for this is that some species are naturally more competitive than the native species due to the environment that they originated from. A study done by Callaway and Aschehoug (2000) examined the establishment of diffuse knapweed (*Centaurea diffusa* Lamarck) in North America and how it compared to establishment against its' natural competitors. They found that when *C. diffusa* was introduced into an environment with three different native species the overall biomass of these native species decreased significantly, while the biomass of *C. diffusa* was not limited by competition. It was concluded that species that faced and escaped tough competition in their native range are better suited for establishment in novel environments (Callaway and Aschehoug 2000).

This factor is often combined by researchers with the theory that introduced species have no natural predators to keep them controlled which leaves more resources for the introduced species and helps with the establishment of the species (Allendorf and Lundquist 2003). Siemann and Rogers (2001) conducted a study on the invasive tree species Chinese tallow tree (*Sapium sebiferum*(L.) Roxb.) and its ability to out-compete native species. The study tested the hypothesis that since introduced species evolve without predators they can increase the allocation of resources to growth and/or reproduction mechanics – often referred to as the *Greater Reproductive Potential Hypothesis* (Cronk and Fuller 2001). The study found that invasive *S. sebiferum* grew to larger sizes and produced a larger seed crop but had lower quality leaves with minimal defence mechanisms compared to the native species (Siemann and Rogers 2001). This agrees with the hypothesis that invasive species are able to evolve under different situations and develop a competitive advantage and out-compete native species (Blossey and Nötzold 1995; Siemann and Rogers 2001). However, this change might be temporary and as native predators begin to target the new species resource allocation might shift towards increased defensive measures (Siemann and Rogers 2001). These results lend themselves to the idea that invasive species experience a genetic adjustment period before an outbreak occurs (Siemann and Rogers 2001).

Another proposed reason for why invasive species are able to establish themselves and out-compete their native counterparts is by using a process known as allelopathy. This process entails the release of phytotoxins by the invasive plant to suppress or kill neighboring plants (Callaway and Aschehoug 2000).

APPROACHES TO INVASIVE SPECIES MANAGEMENT

One proposed solution to the management of invasive species is the introduction of chemical or genetic variation into the population. An example from Holway *et al.* (2002) examined the invasion of introduced Argentine ants (*Linepithema humile* Mayr) into a new environment. The ants were able to out-compete native ant species due to reduced genetic diversity; the decreased genetic diversity resulted in them having more cooperation between colonies which allowed them to more easily repopulate and spread (Holway *et at.* 2002). The authors suggested that by introducing genetic variation into the population which encourages aggression between colonies, this advantageous trait will be constrained (Holway *et al.* 2002). This management approach is limited in the ability to manage for invasive plant species due to the ability for many plants to adapt.

One of the most used methods to determine if species will become invasive or to determine the potential success of the species, is through predictive modeling. Models that are designed to forecast the spatial spread of the species rely heavily on an understanding of the current conditions that the species is presently in and most attempts to predict the success of an introduced species regularly ignore the potential for genetic change and adaptation to the new environment (Allendorf and Lundquist 2003; Dullinger *et al.* 2009).

There are many factors that could trigger evolution for an introduced species. For example, founder effects, genetic drift, stress-induced rapid evolution, and the new environment in general may factor into the evolution of the species (Allendorf and Lundquist 2003). According to a report done by Sakai *et al.* (2001), adaptation does not explain all examples of success for invasive species, however. In some cases, invasive species demonstrated a specific genetic characteristic: phenotypic plasticity (Sakai *et al.* 2001). This characteristic allows for the immediate adjustment to different habitats and environments and makes the process of accurately predicting species success difficult

(Sakai *et al.* 2001). The prediction also relies on the notion that the geographic distribution of the species and the requirements of the species are in equilibrium; however, as mentioned by Dullinger *et al.* (2009), invasive species are by nature not in equilibrium. Modeling for species success requires models to be calibrated and cross-referenced with data from the species' native ranges.

The most important management strategy suggested by researchers is not the control or eradication of the species but rather the prevention of introductions in the first place (Cronk and Fuller 2001; Holway *et al.* 2002; Allendorf and Lundquist 2003). However, globalization and the trade of goods have increased the amount of species introductions, as well as the frequency of these events (Hulme 2009; Crowley *et al.* 2017). Thus, the need for the formation of a management plan is needed.

The practice of *Invasive Species Management* (ISM) encompasses a vast variety of objectives. These objectives include the overall prevention of species introductions, the mitigation and control of infestations once established, and is interconnected with the formation of environmental policy and practices (Crowley *et al.* 2017). Once prevention becomes infeasible, the formation of a control or management plan becomes paramount.

Cronk and Fuller (2001) explain that there are four main methods used to control the spread of invasive species: physical, chemical, biological, and environmental management. These methods are often used in conjunction with each other and are part of a larger system known as *Integrated Pest Management* (IPM). IPM is the practice of preventing or reducing the damage caused by pests by utilizing a strong scientific understanding of the species and combining it with a variety of ecologically and economically sustainable approaches and control methods (Sherman 2015). Formulating a control plan and prioritizing species to manage is an important step towards the successful management of invasive species.

Recently introduced species represent the highest priority for management, but due to the scarce amount of resources available for municipalities, the management of invasive species often gets placed on the back burner (Cronk and Fuller 2001; Sherman 2015). The ability to implement a management plan relies on a stable source of funding and often funding is only obtained once a species is well established.

Prioritizing areas to conduct control methods is another important component of IPM. Prioritizing an area that has little previous invasive species presence, but is considered highly at-risk for invasions should receive higher priority in selection. A study conducted in New Zealand found that of nature reserves studied (n=95), the most at-risk of invasion were small areas with a high boundary-to-area ratio that were in close proximity to roads and/or railways (*e.g.* pathways for entry) (Cronk and Fuller 2001).

The four methods described by Cronk and Fuller (2001) work better in combination with one another; these methods are physical (manual), chemical, biological, and environmental management. Physical control methods are rudimentary and often used by homeowners to control spread on their own property. Examples of physical control methods include hand-pulling, mowing/cutting, and digging/excavation. This method of control is effective against species that do not regenerate from rhizomes, but some species are able to regenerate and require either continuous physical control (*e.g.* repeated mowing/slashing to weaken or degrade the rhizomes), or a combination of physical and chemical control (*e.g.* cut and spray) (Cronk and Fuller 2001; Anderson 2012a).

Chemical control represents the use of herbicides and pesticides to manage the growth and spread of invasive species. Herbicides such as glyphosate are often used to control large patches of invasive species. Application of chemical control methods can be done using multiple methods such as notching, basal bark application, stem injection, or via a foliar spray. Herbicides impact the ability for a plant to grow by interrupting vital system functions such as photosynthesis (Hall *et al.* 2014). An example of this is glyphosate which is one of the most common herbicides in the world. Glyphosate is a non-selective herbicide, which means it will kill most plants it touches (Hall *et al.* 2014). It does this by preventing the creation of certain proteins that are needed for plant growth by stopping a specific enzyme pathway - the shikimic acid pathway (Hall *et al.* 2014). However, the use of chemicals and herbicides in the management of invasive species is a contentious topic and their detrimental effects have been documented by numerous studies (Messing and Wright 2006; Crowley *et al.* 2017).

Another control method is the management of the environment to reduce chance of invasions. Examples of this include utilizing fire and prescribed burns to encourage regrowth of native species or by utilizing pastures and grazing animals to feed on the invasive species – native species are often adapted to the frequent grazing (Cronk and Fuller 2001).

The final control method is biological control which consists of the use of the natural predators of the invasive species to combat the spread. Biocontrol, under ideal circumstances, would have little to no effect on local ecosystems due the host-specific nature of the introduced species and represents a smaller long-term management cost than other control measures (Cronk and Fuller 2001; Messing and Wright 2006). However, this method of control has come under scrutiny in the past few decades due to the unintended side effects on non-target organisms (Messing and Wright 2006; Crowley *et al.* 2017). As such, the use of these biological control agents is a heavily debated topic with discussion on whether it does more bad than good for the environment (Cronk and Fuller 2001; Allendorf and Lundquist 2003; Messing and Wright 2006; Crowley *et al.* 2017).

When selecting possible biological control agents, one must ensure that the species is highly host-specific and will not escape and become an invasive species itself. A study done by Louda and O'Brien (2002) which examined the impacts caused by releasing an exotic weevil species, the Eurasian weevil (*Larinus planus* Fabricius), to combat the spread of the introduced and invasive plant Canada Thistle (*Cirsium arvense* (L.) Scopoli). The study found that while the weevil was believed to be host-specific, testing was done in a laboratory setting and was not able to account for a wide range of characteristics found in the environment (Louda and O'Brien 2002; Allendorf and Lundquist 2003). Louda and O'Brien (2002) found that while the weevil was supposed to only target the invasive Canada Thistle, it was also actively attacking the native Tracy's Thistle (*Cirsium undulatum* (Nutt.) Spreng. *var. tracyi* (Rydb.) S.L. Welsh). The study concluded that the use of biological control measures had a high risk-to-benefit ratio and that better evaluation of potential effects should be conducted. The need for enhanced regulatory oversight was also stated (Louda and O'Brien 2002; Allendorf and Lundquist 2003).

The topic of ISM and social differences was examined by Crowley *et al.* (2017) who described ISM as a "controversial" topic; the extensive use of pesticides and biological control agents against invasive species is one area where debate arises. These differences are clearly seen under the primary approach to many management decisions. The idea that burden of proof rests on the shoulders of scientists and policy-makers was examined by Callon (1999) who looked at the role of the lay person in disseminating knowledge. Callon (1999) hypothesized that there existed a model – the public education model – that explained the need for the lay person to trust researchers. The model contends that the differences in opinions between lay people and scientists/policy makers was based on differences in knowledge; the knowledge of a lay person was often based on beliefs and superstitions and scientific knowledge needed to change this mindset before it could begin to reach the forefront of public opinion. This model was used by Crowley *et al.* (2017) to describe the current approach of top-down decision making to invasive species management. The public education model involved experts making management decisions based on available evidence and informing decision makers who needed to then "convince" the public that it is the best option (Crowley *et al.* 2017). This form of management did not account for differences in social values or in the perception of risk.

The evolution of invasive species management has begun to move away from that method and to incorporate consultation into the planning phase. The beginning of this form of management incorporates the public education model with experts evaluating the evidence and providing opinions but decision makers consult with potential interested parties to scope the range of social values (Crowley *et al.* 2017). This method of management, when done properly, can help balance social values with expert opinion and scientific knowledge. However, there exists an issue of representing all parties equally in the process and, as described by Crowley *et al.* (2017), this is not always possible and can result in heightened conflict.

An example of this need for balance can be seen in the management process for the rodent eradication program for Lord Howe Island in Australia (Crowley *et al.* 2017). The program raised concerns from individuals with many different values and, as such, parties that felt underrepresented delayed the process of the program (Crowley *et al.* 2017). In an effort to streamline the ISM process and limit conflict, Crowley *et al.* (2017) suggested that early, inclusive, public consultation was paramount.

INVASIVES IN THUNDER BAY

Understanding how certain species establish and invade areas is an important aspect of forming a successful management plan. According to EcoSuperior (2020), the "top-five most wanted" invasive plant species found in the Thunder Bay area include: Invasive Phragmites (*Phragmites australis* (Cav.) Steudel), Wild Parsnip (*Pastinaca sativa* L.), Japanese Knotweed (*Reynoutria japonica* (Hout.) Ronse Decraene), Garlic Mustard (*Alliaria petiolate* (Marschall von Bieberstein) Cavara & Grande), and Himalayan Balsam (*Impatiens glandulifera* Royle).

Invasive Phragmites

Invasive Phragmites (*Phragmites australis)* is considered the most invasive species in Ontario and many provincial ministries and organizations are dealing with the spread and invasion of this species (NCC n.d.) Phragmites is a perennial grass that frequently invades and displaces native species in wetlands throughout North America (OMNR 2011; Quirion *et al.* 2018; EcoSuperior 2020). This species leads to lowered biodiversity, higher flood risk, and lower wildlife habitat levels (OMNR 2011; EcoSuperior 2020). It is able to colonize vast areas via clonal expansion – the biomass of the species is largely found underground in an extensive rhizome system. These vast systems are able to produce up to 200 stems/m^2 with approximately two thirds of the species biomass allocated to this rhizome system, often reaching depths of two metres (OMNR 2011; Quirion *et al.* 2018). Seeds are dispersed by wind, water, and by attaching to migrating waterfowl species (Quirion *et al.* 2018).

A vast number of reasons for the species ability to colonize areas have been given. The ability for invasive Phragmites to easily out-compete native species is likely due to a combination of many factors. These factors include the competitive ability of the species due to the absence of natural predators and also the use of allelopathy to prevent and limit encroachment by neighboring species (Uddin *et al.* 2017). The development of roads and highway corridors also creates prime habitat for Phragmites, and as such the species has become a species of special concern for transportation ministries (Quirion *et al.* 2018). The species prefers standing water – such as drainage ditches alongside transportation corridors – but can survive in low water areas due to the extensive root systems of the species (OMNR 2011).

Due to its pervasive root and rhizome system, the OMNR (2011) recommends the use of multiple control measures for Phragmites. It is suggested that an IPM plan is done that determines the ideal control measures, and takes follow-up and monitoring into consideration. The suggested control approach includes cutting the area, applying herbicide, and prescribed burning, as needed (OMNR 2011). However, research has been done surrounding the use of biological control agents (Blossey and Casagrande 2016; Blossey *et al.* 2020). Blossey *et al.* (2020) investigated the use of biological control for invasive Phragmites for two decades before proposing a plan to the governments of Canada and the United States. This research included examining the benefits of introducing the biological control agent (*i.e.* stopping the spread of invasive Phragmites) while attempting to predict risk to native species. The use of biological control through the release of two stem-boring moth species - *Archanara geminipuncta* Haworth and *A. neurica* Hübner - was proposed by Blossey *et al.* (2020) and accepted by regulatory agencies in Canada and the United States. However, as mentioned before, the topic of biological control raises concerns and debates over the impact on native species. Kiviat *et al.* (2019) warned about the release of non-native species into the environment, citing research that showed that the two moth species, *A. geminipuncta* and *A. neurica,* were not host-specific to invasive Phragmites and that research was not done under actual environmental conditions. Regardless of debate, information on the suggested control of species is constantly evolving and any IPM plan should consider a variety of options based on ecologically-sound knowledge.

Wild Parsnip

Wild Parsnip (*Pastinaca sativa)* is thought to have been introduced to North America following European settlement as a crop species due to the edible tap root. However, as with many introduced species, it escaped cultivation and has established as an invasive species throughout North America (Cain *et al.* 2009; Tassie and Sherman 2014). The species reproduces through seed production entirely and, as such, can be easily maintained or controlled with recurring manual control methods (Baskin and Baskin 1979; Cain *et al.* 2009; Tassie and Sherman 2014). The species represents a significant risk to public health due to the presence of chemicals known as furanocoumarins, which are primarily meant to deter predation by herbivores (Averill and DiTommaso 2007; Tassie and Sherman 2014). However this chemical can also cause a reaction in humans known as phytophotodermatitis which causes patches of redness, blisters, or burn-like rashes to appear on the skin when an individual comes into contact with the sap in the presence of sunlight (Averill and DiTommaso 2007; Tassie and Sherman 2014). These reasons have led to the species being considered a noxious weed (Cain *et al.* 2009).

Wild parsnip frequently invades disturbed sites such as rights-of-way, railway embankments, shorelines, the sides of roads and trails, in ditches, forest clearings, abandoned mine sites (Cain *et al.* 2009; Tassie and Sherman 2014). It is also found in pastures, meadows, and along edges of agricultural fields (Baskin and Baskin 1979; Tassie and Sherman 2014).

Manual control methods are often sufficient to stop or limit seed dispersal. The use of mowing, cutting, and removal can help control the species, but timing is important. Mowing should occur between May-June to prevent the production and spread of seeds (Cain *et al.* 2009; Tassie and Sherman 2014). The use of chemical control methods is also a suggested control measure; herbicides such as glyphosate, 2-4-D, and others have been reported to be successful in containing the species (Cain *et al.* 2009). As with manual control methods, chemical controls should be conducted in accordance with the life-cycle of the plant to reduce seed production and dispersal (Tassie and Sherman 2014).

Japanese Knotweed

Japanese knotweed (*Reynoutria japonica*) was introduced into the United States in the late-1800s as a horticultural plant. It was typically used as a species to stabilize banks and mitigate erosion (Anderson 2012a). Since its escape from cultivation, it has been listed as one of the world's top-100 most invasive plants due to its unique reproductive methods and ability to quickly colonize in new environments (Murrell *et al.* 2011; Anderson 2012a). The first recorded case in Ontario occurred in 1901 near Niagara Falls and has since then expanded its range throughout southern Ontario (Anderson 2012a).

The presence of this species significantly alters the local biodiversity as it colonizes and grows in dense clusters. Studies have shown that sunlight penetration of areas colonized by knotweed is reduced by approximately 90% which effectively reduces the native ground cover to near 0% (Maerz *et al.* 2005; Anderson 2012a). The results of this reduced diversity is well documented and it is noted that levels of wildlife are dramatically impacted. A study done by Maerz *et al.* (2005), which examined the impact of biological invasions on the degradation of terrestrial habitats and the specific impacts caused to the native Green Frog (*Rana clamitans* Latreille), hypothesized that the introduction of Japanese knotweed into an environment caused adverse effects to the structure and community. The study proposed the idea that the presence of Japanese knotweed indirectly causes a decline in the level of invertebrates present, thus lowering the amount of food available for the Green Frogs (Maerz *et al.* 2005).

Japanese Knotweed reproduces through vegetative methods. It forms an extensive underground network of rhizomes that can reach depths of 2 m and extend up to 20 m in length (Weston *et al.* 2005). The species reproduces through these rhizomes or through stem fragments which are transported by water or through human movement (soil, machinery, etc.) (Weston *et al.* 2005; Anderson 2012a). Many studies have been done to examine the regeneration and reproductive rates of Japanese knotweed. One of these studies examined the relative rates of regrowth based on different lengths of rhizome segments. This study, done by Sásik and Elias (2006), showed that rhizome segments of even 2 cm can grow new shoots 60% of the time, and this percentage increased with an increase in rhizome length. The establishment of this species is also aided through the use of allelopathy (Murrell *et al.* 2011).

These factors cause major difficulties in controlling the species and requires a thorough, comprehensive IPM plan that accounts for all possibilities (Anderson 2012a).

Suggested control contains a variety of methods, however, Murrell *et al.* (2011) suggest that even just one cutting can help limit the production of new growth and promote native growth instead; the study found that if the main shoots were cut even once the rhizome biomass was suppressed by 75% and the biomass of native species increased by 75%. These numbers increased with repeated manual cutting virtually "stalling" the growth of the species (Murrell *et al.* 2011). Combining the use of manual control methods with chemical control methods can increase the likelihood of success dramatically (Anderson 2012a).

Garlic Mustard

Garlic mustard (*Alliaria petioalta*) was originally introduced into North America as a food source for settlers but escaped cultivation and began invading forests, agricultural areas, and residential lands (Anderson 2012b). Garlic mustard has the unique ability to invade and establish in mature second-growth forests, habitats which are often thought of as being fairly resistant to invasions (Meekins and McCarthy 1999). Garlic mustard forms dense monocultures which are able to drown out the competition (Anderson 2012b). There are mixed reviews on the allelopathic properties of the species, with some researchers suggesting that the species uses allelopathy (Vaughn and Berhow 1999; Anderson 2012b), while others say that it is unclear whether it does play a role in the establishment of the species (Cipollini and Cipollini 2016). Regardless of the way it establishes, the species represents a significant threat due to its ability to spread and cover ground easily. Garlic mustard disperses seed relatively close to the parent plant, and dispersal over long-distance is often the result of transportation by humans, animals, or machines (Anderson 2012b). Victoria Nuzzo (1999) conducted a study examining the invasion pattern of garlic mustard and found that, on average, it spreads at a rate of 5.4 m per year. However, this rate varied depending on the level of disturbance on the site (Nuzzo 1999).

The control of garlic mustard is simple and the roots are very shallow which allows for manual control methods to be used. Organizations, such as EcoSuperior, often have “hand-pull events” to remove the species from an area (EcoSuperior 2020). However, the species is able to repopulate from a single plant via self-pollination so control measures need to be done in a thorough method (Anderson 2012b). As such, it is recommended that control methods be undertaken for at least five years (Anderson 2012b). Hand pulling is effective against small populations but for large populations it is best to use mowing or other manual methods (Anderson 2012b). Chemical control can also be used, however, using manual control methods is likely as effective and cheaper (Anderson 2012b).

Himalayan Balsam

Himalayan balsam (*Impatiens glandulifera*) is an annual plant native to the Himalayan foothills but due to the showy nature of the plant was introduced into the UK and North America as an ornamental (Clements *et al.* 2008; Varia *et al.* 2016; Ellison *et al.* 2020). This species commonly grows along riverbanks and in riparian zones, however, it can tolerate a wide range of environmental conditions, including full shade, and represents a significant threat to these areas (Clements *et al.* 2008; Kelly *et al.* 2008; Varia *et al.* 2016; Greenwood *et al.* 2018; Sullivan and Holliman 2019). Himalayan balsam grows to heights of up to 2 m and is able to outcompete native species by luring away pollinators from native plants, thus lowering their seed production and fitness (Chittka and Schürkens 2001; Ellison *et al.* 2020). It is a prolific seeder – up to 2,500 seeds/plant - and spreads them using a specialized seed dispersal technique where the seed capsule explosively expels the seeds of distances up to 7 m (Balogh 2008; Clements *et al.* 2008; Varia *et al.* 2016; Ellison *et al.* 2020). This ability often causes seeds to land in waterways, which act as the primary mode of transportation for the species (Clements *et al.* 2008; Greenwood *et al.* 2018). Its seeds are also specialized and can begin germination even with the seeds underwater (Balogh 2008; Kelly *et al.* 2008)

Himalayan balsam represents a threat to riparian zones due to its rapid growth and annual life cycle. The plant outcompetes native species to establish itself as the dominant species on riverbanks and upon dying at the end of the growing season leaves the banks barren and vulnerable to erosion (Clements *et al.* 2008; Varia *et al.* 2016; Greenwood *et al.* 2018; Ellison *et al.* 2020). Himalayan balsam also has an observed impact on invertebrate communities. A study done by Tanner *et al.* (2013) examined the impact caused by its rapid colonization and found that, due to the dense canopies created by the monocultures of Himalayan balsam, biomass of native species was negatively impacted which had an adverse effect on the abundance of herbivorous foliage and ground-dwelling invertebrates (Tanner *et al.* 2013). The study hypothesized that this decline was caused due to the invasive plant outcompeting native species for sunlight and nutrients (Tanner *et al.* 2013).

Organizing an IPM plan for the control of Himalayan balsam requires careful planning and understanding of the species. Clements *et al.* (2008) highlight the species' sensitivity to glyphosate, however, due to the highly sensitive nature of riparian zones that the species often grows in, significant consideration must be given to management plans. The suggested method of control by Clements *et al.* (2008) was through the use of manual control methods; cutting the main stem or hand pulling the plant was determined to be successful in controlling the reproduction and spread of the species. Due to the dispersal of seeds along waterways, it was also suggested to prioritize upstream populations first (Clements *et al.* 2008; Kelly *et al.* 2008). The root system only penetrates the soil 10-20 cm so overall soil disturbance caused by removal is minimal (Balogh 2008; Clements *et al.* 2008). The removal of Himalayan balsam should be accompanied by the planting of native species to restore native biodiversity and prevent bank collapse and erosion (Clements *et al.* 2008; Kelly *et al.* 2008).

Research into potential biological control methods for the species is underway with searches for natural enemies beginning in 2006 (Varia *et al.* 2016; Ellison *et al.* 2020). Insect species were ruled out by researchers due to the wide host range exhibited by the species (Varia *et al.* 2016; Ellison *et al.* 2020). Because of this, research turned to fungi and various pathogens that cause damage to Himalayan balsam. A rust fungus, *Puccinia komarovii* Tran. *var. glanduliferae,* was found to be a macrocyclic, autoecious species that was host specific to Himalayan balsam (Varia *et al.* 2016; Ellison *et al.* 2020). The rust fungus causes damage to the host plant during two stages of growth. During the initial stage of growth, the fungus infected the stems of young seedlings and killed them. It impacted mature plants by reducing the available photosynthetic area causing the host to divert nutrients and resources away from reproductive functions and effectively limiting seed production (Varia *et al.* 2016; Ellison *et al.* 2020). However, further research is required to fully quantify the impact and success rate of the fungus as a biological control agent (Varia *et al.* 2016; Ellison *et al.* 2020).

MATERIALS AND METHODS

Due to the cross-jurisdictional nature of invasive species management, a review of nineteen urban forest management plans (UFMP) and one integrated pest management program (IPM) from municipalities across Canada was done to examine the extent and scope of invasive species management done in an urban environment. A completed list of these plans can be found in Appendix I. These plans were selected based on their accessibility from an internet search. The information gathered from the examination was compared with the reviewed literature to examine strengths and weaknesses of management systems. Information was obtained from the City of Thunder Bay to determine the level of management currently being done on a local scale, and what the outlook for the City is. Information from EcoSuperior and the City of Thunder Bay was used to determine the "top-five" invasive plant species found in the city. This information was used in conjunction with the reviewed literature to determine possible management and control measures and form recommendations for the City.

The information gathered from the different sources was combined with the reviewed literature to assess the threats associated with each species, and how the City of Thunder Bay can enact better management plans through species prioritization. The data/information is summarized into recommendations to the City. Searches for literature were based on an internet search of terms and themes. These terms included: "invasive species management", "biological impact of invasive species", and "invasive species impacts". Specific searches were done to examine the biology and impacts caused by the top-five invasive species.

Within each UFMP and IPM, a cursory search of key terms was done to examine the relevant information within. These terms included: “invasive”, “introduced”, “pest”, “Himalayan balsam”, “Japanese knotweed”, “garlic mustard”, “phragmites”, “wild parsnip”, “IPM”, “control measures”, and “forest health”. This information was used to determine the primary management strategies utilized by Canadian municipalities.

DISCUSSION

The level of management for invasive species varies across all the plans examined. Some plans contain no references at all to invasive species management (*i.e.* the Town of Bracebridge), while some are more in-depth (*e.g.* the City of Toronto and the City of Mississauga). When it comes to managing for invasive species, it is important to prioritize areas and species in general. Because, as mentioned by Cronk and Fuller (2001) and Sherman (2015), the levels of resources available for the management varies between municipalities.

The complete eradication of invasive species is likely unobtainable for the City of Thunder Bay due to its large, sprawling nature, and limited resources. The current UFMP for Thunder Bay (drafted in 2011) does not mention specific invasive species at all and is focused more on the emergence and potential destruction of EAB in the area (Davey Resource Group 2011). However, the spread and known devastation caused by EAB outbreaks has led to invasive species management becoming a priority for the City.

A survey done by the Invasive Species Centre (ISC) in 2019 showed the estimated economical impact of invasive species on municipalities in Ontario. This survey showed that the average expenditure for invasive species management for municipalities was $218,148 per year with nearly all of it being dedicated to the control and management of the species; the rest of the expenditure was used for the detection and overall prevention of species introductions (Vyn 2019). Emerald ash borer represented the highest cost associated with invasive species management among

Ontario municipalities, however, of the top-six species listed in the survey, two of them are plant species found in Thunder Bay – phragmites and wild parsnip (Vyn 2019).

The City currently has an Emerald Ash Borer Services Coordinator who is in charge of emerald ash borer monitoring and assessments and prescribing treatments. This coordinator, Robert Scott, is also taking a leading role in the formation of the City's Invasive Plant Management Strategy (Robert Scott, pers. comm., Nov 29th, 2019). This strategy is being developed with information gathered through the Regional Public Works Commissioners of Ontario (RPWCO) Committee – a collaborative initiative with a subsection related to urban forestry. This Committee allows for the sharing of knowledge relating to the many issues urban forests face. With most members representing cities and municipalities in southern Ontario, they are able to provide first-hand knowledge about the management of species that may not have migrated north yet (Robert Scott, pers. comm., Nov 29th, 2019).

The current extent of invasive species management in Thunder Bay is still primarily EAB management, however, there are initiatives in place for invasive plants. Currently, the City's Forestry & Horticulture department has been collaborating with EcoSuperior to manage three of the five listed species (Robert Scott, pers. comm., Nov 29th, 2019). These species are phragmites, Himalayan balsam, and garlic mustard. The City does not currently utilize chemical spraying and instead relies entirely on physical control measures. Current management that has been undertaken include mowing of a potential phragmites stand and mowing of two patches of Himalayan balsam in McVicar Creek (Robert Scott, pers. comm., Nov 29th, 2019). According to an article published in the Chronicle Journal (2019), the City spent approximately $5,000 in 2019 on invasive plant control although the current budget for EAB control is approximately $700,000. EcoSuperior and the Thunder Bay Field Naturalists host garlic mustard and Himalayan balsam pulls annually in the McVicar Creek area (Robert Scott, pers. comm., Nov 29th, 2019).

The species of most concern according to Scott (pers. comm., Nov 29th, 2019), in order of severity are: phragmites, wild parsnip, Japanese knotweed, Himalayan balsam, and finally garlic mustard. These are based on current abundance, threat to local biodiversity and further invasion, and threat to public welfare (*i.e.* wild parsnip causing phytophotodermatitis). The use of EDDMapS (Early Detection and Distribution Mapping System) is combined with traditional ground truthing in order to identify potential invasion sites, and prepare preventative measures. However, this is barebones and a shift toward a more detailed collection system will be necessary to facilitate the appropriate levels of control required (Robert Scott, pers. comm., Nov 29th, 2019).

According to Scott (pers. comm., Nov 29th, 2019), the invasive plant management strategy will focus on the early detection and eradication of species; this is vastly different than the majority of UFMP's examined. Within most of the plans, the identification and detection were not a priority. Rather, most plans displayed a reactive mindset to the detection, instead of a proactive approach. The management of known invasive species was also done on a reactive basis, with most plans listing control measures as being undertaken on an *ad hoc* basis with priority given to species that represent the greatest threat to local biodiversity (*i.e.* the species which have the greatest chance to establish in an area). This is best exemplified under Appendix C of the City of Mississauga UFMP (City of Mississauga 2014). This appendix contains the City's invasive species management plan that was done in collaboration with a nearby conservation authority.

This type of *ad hoc* approach is done usually in response to immediate threats or problems; the City of Lethbridge IPM plan described how the use of control measures only occured *after* the population levels exceeded the acceptable limit and indicated that "economic losses could exceed costs of control" (City of Lethbridge 2014). Control and management outlined in the examined UFMPs indicated that there was an opportunistic approach with management of invasive species occurring along with regular tree maintenance (*e.g.* the City of Guelph), and through beneficial initiatives from community groups (*e.g.* EcoSuperior).

In order to navigate the limited municipal budget for invasive species control, it is suggested that cities make efforts to prioritize selected species and areas to manage. Attempts should be made to prioritize areas that represent the greatest threat for establishment (*e.g.* frequently travelled areas, slopes, areas with little competition) and species that pose the greatest threat to local biodiversity (*e.g.* phragmites). As such, the species prioritization list provided by Scott (pers. comm., Nov 29th, 2019) is consistent with suggestions and recommendations gathered from the examined literature and UFMPs. By prioritizing species and areas, municipalities can achieve the most success with the relatively low budgets.

With the information gathered, there are a handful of recommendations that can be made for the management of invasive plant species within the City of Thunder Bay. The creation and implementation of an invasive plant strategy is a step in the right direction and the on-going collaborative efforts with stewardship groups helps with the goal of early detection and prevention. The top priority for Thunder Bay should be continuing educational outreach on the potential impacts caused by the introduction and establishment of invasive species. The education and awareness of invasive species is important in preventing the spread or establishment. However, there exists an inability to enforce the control of many invasive plant species due to lack of legislation.

Municipalities do not possess the legislative power to enforce the destruction of invasive species, nor can they prevent the intentional planting of them (Shelley Vescio, pers. comm., Oct 31st, 2019). However, there is legislation that provides power and support for controlling invasive species in Ontario. If a plant is listed as a "noxious weed" in Ontario under the *Weed Control Act*, R.S.O 1990 then control measures can be enforced. These species are designated as noxious weeds due to their ability to negatively affect public health, the health of livestock, or causing an adverse impact on agricultural production (Weed Control Act 1990). The Act grants the power for designated inspectors to enter property searching for noxious weeds and, if found, they are able to enforce the destruction of the plants.

Out of the five species of concern for Thunder Bay, only one (wild parsnip) is considered a noxious weed under the act (Weed Control Act 1990). The other four species, while representing a threat to local biodiversity, do not pose enough of a threat to public well-being to be considered a noxious weed.

Similarly, the *Invasive Species Act* (2015) provides the power for the control and eradication of invasive species. Under section 23 of the Act, if an inspector working under the authority of the Act determines that an area contains invasive species which has the potential to spread, they may declare the site an "invaded area". Areas designated as being invaded can be prescribed an order that grants the power to authorities to take preventative measures to control and/or eradicate the invasive species from the area (Invasive Species Act 2015 s.27). The Act also grants the power to governmental officials to classify a species as "prohibited" or "restricted". Species that are classified as "prohibited" represent a significant threat to local biodiversity and as such are controlled heavily. Under the Act, no person can bring, or cause a species to be brought, into Ontario a species classified as "prohibited". As well, no person can possess, transport, propagate, buy, sell, lease or trade a species classified as "prohibited" (Invasive Species Act 2015). There are sixteen species classified as prohibited under the *Invasive Species Act* (2015); eight are fish species, three are aquatic overaerates, and five are plant species. However, none of these species are species of concern for the City.

Species designated as "restricted" share similar limitations, and similar power to authorities is granted. However, it is not illegal to possess these species (*e.g.* already growing in the backyard) and unless there is major threat to protected areas (*e.g.* provincial parks and conservation areas), enforcement of removal is limited (Invasive Species Act 2015). Under the Act, four plant species are considered "restricted" and two of them are species of concern for the City: phragmites and Japanese knotweed. As such, the increased awareness brought by education programs should be the top priority.

Educational programs should entail the identification of invasive species, proper reporting methods (*e.g.* EDDMapS), and an introduction to the benefits of native species. The utilization of programs such as the *Grow Me Instead* initiative led by the OIPC is recommended. The *Grow Me Instead* program provides guidance on the selection of suitable native species to plant on homeowner's property. This guide helps with the identification of some invasive species and offers native species alternatives instead. For example, the guide provides information and impacts caused by Japanese knotweed and suggests suitable alternatives (OIPC 2014).

Due to the relatively low presence of invasive plant species currently in the city, resources should be directed to known sites to prevent spread. Should new populations be identified, priority should be given to areas which represent ideal natural areas or areas with important significance. This approach is utilized in the City of Mississauga's invasive plant species management plan. Under the plan, priority is given to areas that represent "flagship" natural areas. This determination is based on a set of criteria which include whether there are provincially threatened or endangered species in the area or if the area is given special designation such as being an Environmentally Significant Area (ESA) (City of Mississauga 2014).

Another criterion, and one that is recommended by the City of Mississauga, is the use of the Floristic Quality Index (FQI). The FQI is determined using Floristic Quality Assessments (FQA) which assigns an ecological value to an area; FQA uses the

Coefficient of Conservatism (C) which are values assigned to local plant species based on their likelihood of appearing in natural habitats in the area (Bourdaghs *et al.* 2006; Freyman *et al.* 2016). Species that have high C values represent species that would have naturally evolved and grown in the natural habitats – this generally lends itself to the notion that FQA metrics are effective at measuring high-value natural areas (Freyman *et al.* 2016). Under this system, non-native species are given a C rating of zero, therefore lowering the overall FQA value. Floristic Quality Index values are derived by weighing the mean C value by the overall species richness (Freyman *et al.* 2016). As such, the FQI rating gives good indication of high priority areas as it includes many of the criterion for the selection of "flagship" areas (City of Mississauga 2014; Freyman *et al.* 2016).

However, databases for this index need to be built for northern Ontario; the article by Freyman *et al.* (2016) mentions databases for Minnesota and southern Ontario which can be extrapolated and revised to reflect local conditions. Regardless of the approach used, proper allocation of resources is required to effectively manage invasive plant species populations. As such, priority areas should be selected. It is also recommended that areas with high levels of human activities be monitored for invasive species as these areas have high social and recreational values to the public.

Within the invasive species of concern, phragmites should be given top priority due to its ability to escape and rapidly establish in new areas. Manual control measures should be employed with mowing of stands occurring in consecutive years to weaken the root system and where possible, chemical control measures should be used in combination. Garlic mustard can be adequately managed through manual control measures also, and the City should aim to maintain and encourage programs through partnerships with environmental stewardship groups in the city.

The management of Japanese knotweed requires vigilance to ensure populations of the species are identified early. As suggested by Murrell *et al.* (2011) and Anderson (2012a), repeated cutting/mowing of the species can essentially stall production, and when combined with other control methods (*e.g.* chemical) the species can be readily managed and contained. The use of chemicals however, as mentioned, is a contentious topic, and as such can be avoided if need be. Vigilant monitoring of the species, and recurring manual control should be enough to contain to spread of the species.

Himalayan balsam can be managed through hand-pulling and other manual methods of control, however, due to the primary method of dispersal being waterways, populations of this species which reside upstream should be managed first (Clements *et al.* 2008; Kelly *et al.* 2008).

Wild parsnip represents a threat to public health, however, there are few confirmed locations of the species. As such, management priority is not high and regular monitoring and manual control measures will be able to sufficiently manage the spread of this species. Should the species be identified in an area with a high chance of public contact, immediate action should be taken to eliminate the population. Along with all control measures undertaken, it is encouraged that native plant species be planted to replace the invasive species to repair local biodiversity and prevent the re-establishment of invasive species. This is of particular concern with Himalayan balsam due to the possibility of riverbank destabilization and erosion; the *Grow Me Instead* guide includes many examples of suitable native replacements.

Recent research has indicated that there are effective biological control methods that can be used to manage Himalayan balsam and phragmites. However, there are risks associated with the release of these biological agents. As such, further research into the regional suitability of the agents, the potential of escape, and the impact on native biodiversity needs to be done before the use is recommended for the City.

CONCLUSION

The rise of globalization has undoubtably led to an increase in species introductions and with changing climates it is obvious that the rate of introductions will continue to increase in northern areas. The City of Thunder Bay currently has few invasive plant species present, but past events have made it obvious that proactive management through preparation and active monitoring can drastically minimize the level of impact caused by species introductions. Large-scale outbreaks such as EAB or Chestnut Blight have made invasive species more mainstream and increased the awareness about the proper management of them. Because of this and by understanding the biology of invasive species, municipalities can better manage them through programs such as integrated pest management. But these programs require adaptive management, and constant examining of emerging studies because the field of pest management is continuously evolving. An example of this can be seen with the management of phragmites and Himalayan balsam – both species have seen new research emerge into potential biological control methods. Examining potential threats (*i.e.* species that have not migrated north yet) also represents an important component of the successful implementation of an invasive plant management program as it allows for proactive management decisions to be made.

The City of Thunder Bay is in an important stage in the management of invasive species. The City cannot do it alone. It needs to be a cooperative effort between the City, community partners and homeowners. With proper support and a good understanding of the key characteristics of the species, Thunder Bay can potentially control and prevent the destruction of local biodiversity.

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APPENDIX

APPENDIX I: LIST OF EXAMINED URBAN FOREST MANAGEMENT PLANS AND INTEGRATED PEST MANAGEMENT PROGRAMS

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